

Use of underpasses by animals on a fenced expressway in a suburban area in western Poland

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Abstract

Expressways act as barriers to animals that block free movement in their habitats, especially when the roads are continuously fenced to prevent collisions between animals and vehicles. Various types of animal passages have been repeatedly studied in terms of their utility, albeit rather less frequently in the suburban environment. We conducted our research in a section of the fenced expressway S3 connecting two closely located cities in western Poland (Lubuskie province). Over the course of one year, we monitored four underpasses intended for small- and medium-sized animals using tracks. The underpasses were inspected weekly. Animal traces most frequently found belonged to roe deer *Capreolus capreolus* (20.9%), red fox *Vulpes vulpes* (15.1%), wild boar *Sus scrofa* (14%), and domestic dog *Canis l. familiaris* (12.4%). Surprisingly, the results of our study indicate that underpasses for small and medium mammals are also used by ungulate mammals. The use of the underpasses varied seasonally, being the highest in spring (37.9%) and the lowest in winter (10.4%). Moreover, seasonal differences in the use of passages were related to particular species/groups of animal species. We found that 22% of animals that entered the passage did not completely traverse it. People accounted for 17.1% of all stated traces in the underpasses. Stagnant water in the underpasses reduced the number of predatory mammals and wild boars using the underpasses but did not affect the activity of roe deer. These studies indicate that animal underpasses located in suburban areas are used by many species of animals despite the activity of humans and domesticated mammals.

Keywords

barrier effect, expressway, suburban area, vertebrate, wildlife underpasses

Introduction

At the global scale, roads have a considerable impact on the surrounding wildlife (Clevenger 2012). Among the most important effects of road infrastructure are the fragmented areas occupied by wild animals and barriers that isolate local animal populations (Forman et al. 2003, Coffin 2007, McGregor et al. 2008, Ascensão et al. 2015, Chen and Koprowski 2016, Andersson et al. 2017). The effect of such barriers on wildlife depends on animal behavior, population distribution, and dispersal capacity (Forman et al. 2003), which applies to many species of animals, especially with regard to modern roads with wide road lanes (Rico et al. 2007). In addition, road traffic is a stressor for wild animals (Navarro-Castilla et al. 2014, Wiącek and Polak 2015).

Another equally important effect of road infrastructure is wildlife mortality due to collisions with vehicles (Trombulak and Frissell 2000). Animal mortality may be attributed to various factors related to their activity in road corridors, for example, crossing the road, settling in the neighborhood of the road, or using the road as a feeding ground (Sabino-Marques and Mira 2011). Worldwide, this problem (in various degrees) ranges from urbanized and industrialized areas to natural ecosystems and affects many animal species (Hels and Buchwald 2001, Hell et al. 2005, Gryz and Krauze 2008, Borkovcová et al. 2012, Brzeziński et al. 2012, Hothorn et al. 2012, Ruiz-Capillas et al. 2015, Visintin et al. 2016).

With new investments in road infrastructure, various solutions are used to prevent these collisions and to simultaneously allow animals to move around the area that the road crosses. The solutions include tunnels (e.g. for amphibians), underpasses, and overpasses. The size of a passage affects its usage by various animal species that show selectivity in this aspect, especially large animals (van Bohemen 1998, Gloyne and Clevenger 2001, Ford et al. 2017). The passages for animals significantly reduce the effect of fragmentation of habitats, improve the communication between populations, and limit wildlife activity within the road lane (Simpson et al. 2016). Also, road fencing or a combination of fencing and crossing structures reduce the risk of animal-vehicle collisions (Ascensão et al. 2014, Huijser et al. 2016, Rytwinski et al. 2016).

The usage of the passages by wildlife also depends on the location of the passages in the environment as well as their sizes and shapes. In numerous publications on the use of underpasses by animals, the problem of animals rejecting the option of moving under the road has not been raised. It is unknown how many individuals withdraw from passing under the road by using an underpass after having entered it. Furthermore, there are no known factors that have been reported to affect such animal behaviors.

This study was conducted with the aim of estimating the usage of underpasses under an expressway by wildlife in a suburban environment. We tested the hypotheses that (1) the number of animals that use underpasses varies during the year; (2) underpasses that

differ in technical parameters are not used by animals to the same extent; (3) the stagnation of rainwater in underpasses does not affect their use by large animals, such as roe deer and wild boar; (4) animals that intend to migrate rarely abandon their attempts during the action; and (5) human activity in underpasses adversely affects their use by wildlife.

Materials and methods

Study area

This research covered a section (16 km) of the S3 expressway located in western Poland between the cities Zielona Góra (138,898 inhabitants) and Nowa Sól (39,459 inhabitants; Figure 1). The road is a part of the international E65 road, which is the element of the trans-European transport corridor. The S3 road follows the meridian line from the Baltic seaports Świnoujście-Szczecin in the north at the western Polish border to reach the border with Czechia in the south. Via ferry lines, this route provides the shortest direct connection between southern Scandinavia and the northern part of Czechia. In 2010, the average traffic on this route amounted to 16,891 vehicles/day (GPR 2010).

The section of the expressway that was monitored in this study was built in 2006–08, and it was the first two-lane road of an expressway type in the western part of Poland. The second two-lane roadway was built after the present studies have been completed, in 2015–18, and the construction included the reconstruction of animal passages. During the monitoring period of our study, the roadway was fenced and separated the surrounding areas, thus preventing animals from entering the road lane. The fence is 220 cm high. The mesh size is 20×30 cm. From the ground up to 100 cm, the mesh is dense and is of 5×30 cm size. It allows medium and small mammals to enter the road. During our study, we did not conduct any survey on the mortality of animals caused by collisions with vehicles.

The road runs in a lowland landscape. Vegetation on both sides of the road includes mainly pine forests, with the dominant Scots pine *Pinus sylvestris*, and an admixture of black locust *Robinia pseudoacacia* and Norway maple *Acer platanoides*. The undergrowth comprises shrubs such as: bird cherry *Padus avium*, alder buckthorn *Frangula alnus*, young Norway maple, and northern red oak *Quercus rubra*. In several places, the road adjoins meadows with willows *Salix* spp. Monitored passages are located in the same environmental conditions.

Species of medium- and large-sized mammals that occur in the area near the expressway and were included in hunters' inventories of the years 2012–13 include: red deer *Cervus elaphus* (19 individuals), roe deer *Capreolus capreolus* (330 individuals), wild boar *Sus scrofa* (70 individuals), red fox *Vulpes vulpes* (35 individuals), pine marten *Martes martes* and stone marten *Martes foina* (20 individuals), European badger *Meles meles* (19 individuals), raccoon dog *Nyctereutes procyonoides* (20 individuals), European polecat *Mustela putorius* (11 individuals) European hare *Lepus europaeus* (29 individuals) (data available from Polish Hunting Association in Zielona Góra).

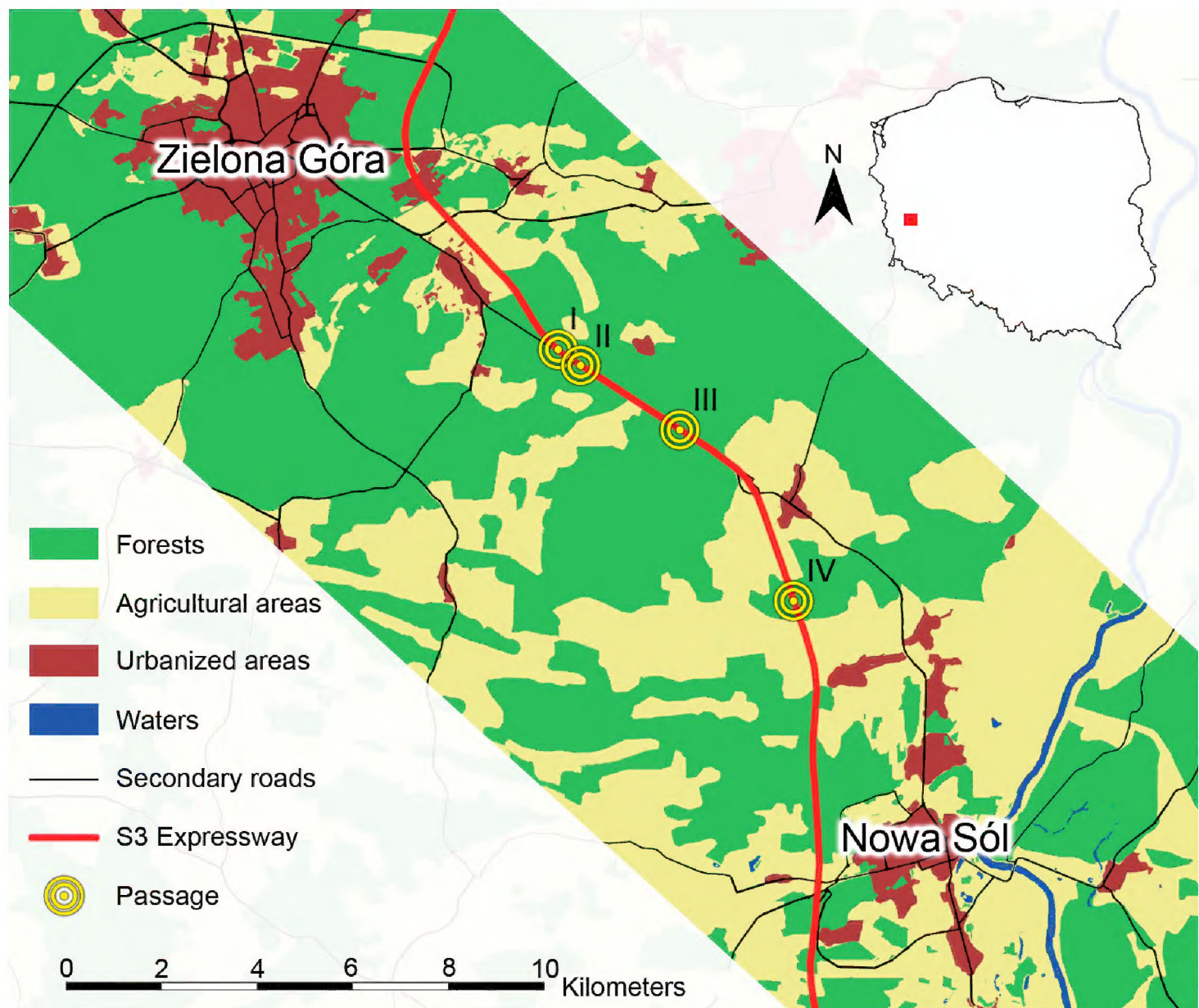


Figure 1. Distribution of monitored underpasses under the S3 expressway in western Poland.

Monitoring of underpasses

This research included four underpasses for small- and medium-sized animals (Figure 2). The longest distance between the first and fourth underpass was 6.6 km. The monitoring was carried out systematically once a week from April 1, 2012 to March 31, 2013. In total, 52 checks were carried out at each underpass. Each monitoring event comprised two visits on consecutive days. On the first visit, the sandy ground on the entire area of each underpass was raked (Figure 3). The track-beds in underpasses were 37 m long, 3–6 m wide, 196 m² raked area (underpass I), 17 m long, 4 m wide, 64 m² raked area (underpass II), 40 m long, 2 m wide, 71 m² raked area (underpass III), and 25 m long, 7 m wide, 160 m² raked area (underpass IV). On the second visit we identified the animal species based on the animal footprints on the ground. Identification of the footprints was made following Romanowski (1998) and Jędrzejewski and Sidorovich (2010). Furthermore, we monitored the movement of people in the underpasses.

We did not distinguish between species that – due to their similar size, body structure, and movement – could be easily misidentified. We described these as groups of



Figure 2. Monitored S3 expressway underpasses in western Poland.



Figure 3. Preparation of track beds for survey of animals' activity in underpass in S3 expressway.

species: large mustelids: pine marten, stone marten, European polecat; small mustelids: stoat *Mustela erminea*, and least weasel *Mustela nivalis*; small mammals: rodents from genus *Apodemus* and *Microtus*, and soricomorphs.

The monitored underpasses are intended to aid small- and medium-sized animals. Along the section of the road we monitored, there are no other passages. The underpasses are elliptical in shape. They consist of sections characterized by different size parameters. Between the sections, there are openings in which animals are exposed to traffic-related factors (e.g. noise, lighting; Table 1).

Table 1. Type, dimensions, openness index (OI) and function of the monitored crossing structures in the S3 expressway in western Poland.

Number of crossing		Dimensions (m)				Crossing type
		Width	Height	Length	OI	
I	section Ia	6.4	2.2	8.1	1.74	underpass for medium mammals
	section Ib	6.4	2.5	16.2	0.99	
	section Ic	3.1	1.9	13.1	0.45	
II		3.8	1.5	16.8	0.34	underpass for small mammals
III	section IIIa	1.75	1.7	7.8	0.30	drainage
	section IIIb	1.75	1.45	18.7	0.14	underpass for small mammals
	section IIIc	1.9	1.1	13.1	0.16	
IV	section IVa	6.5	2	7.3	1.78	underpass for medium mammals
	section IVb	6.5	2	17.3	0.75	

We calculated the openness index (OI) according to the following formula:

$$\text{Openness index} = (\text{width} \times \text{height}) / \text{length}$$

We calculated the index of use (UI) of the underpasses for particular animal species/groups by the formula:

Index of use = number of individuals of each species found in the underpass / number of underpass checks

We determined the percentage of a particular species in relation to the total number of individuals found to have used the underpass, and the percentage of individuals of a given species in relation to the total number of recorded animals. We analyzed the variability of wildlife activity in months and seasons: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). We calculated the Shannon Diversity Index (H) for every wildlife underpass.

For the calculations, the R program (R Core Team, 2018) was used.

Results

During the year-round monitoring, we recorded traces of 364 animals in the four underpasses under the S3 road. This translates to an average of seven animals per crossing monitoring event. Of the 15 animal species/groups we found, the most frequently recorded animals included: roe deer (UI = 1.46), red fox (UI = 1.05), and wild boar (UI = 0.98). Moreover, the underpasses were intensively used by domestic dogs *Canis l. familiaris* (UI = 0.86; Figure 4).

The use of the underpasses by wildlife was variable. The most intensively used underpasses were I (UI = 2.70) and IV (UI = 2.42). Underpasses II and III were used less frequently, and their utilization rate amounted to 0.94 and 0.92, respectively.

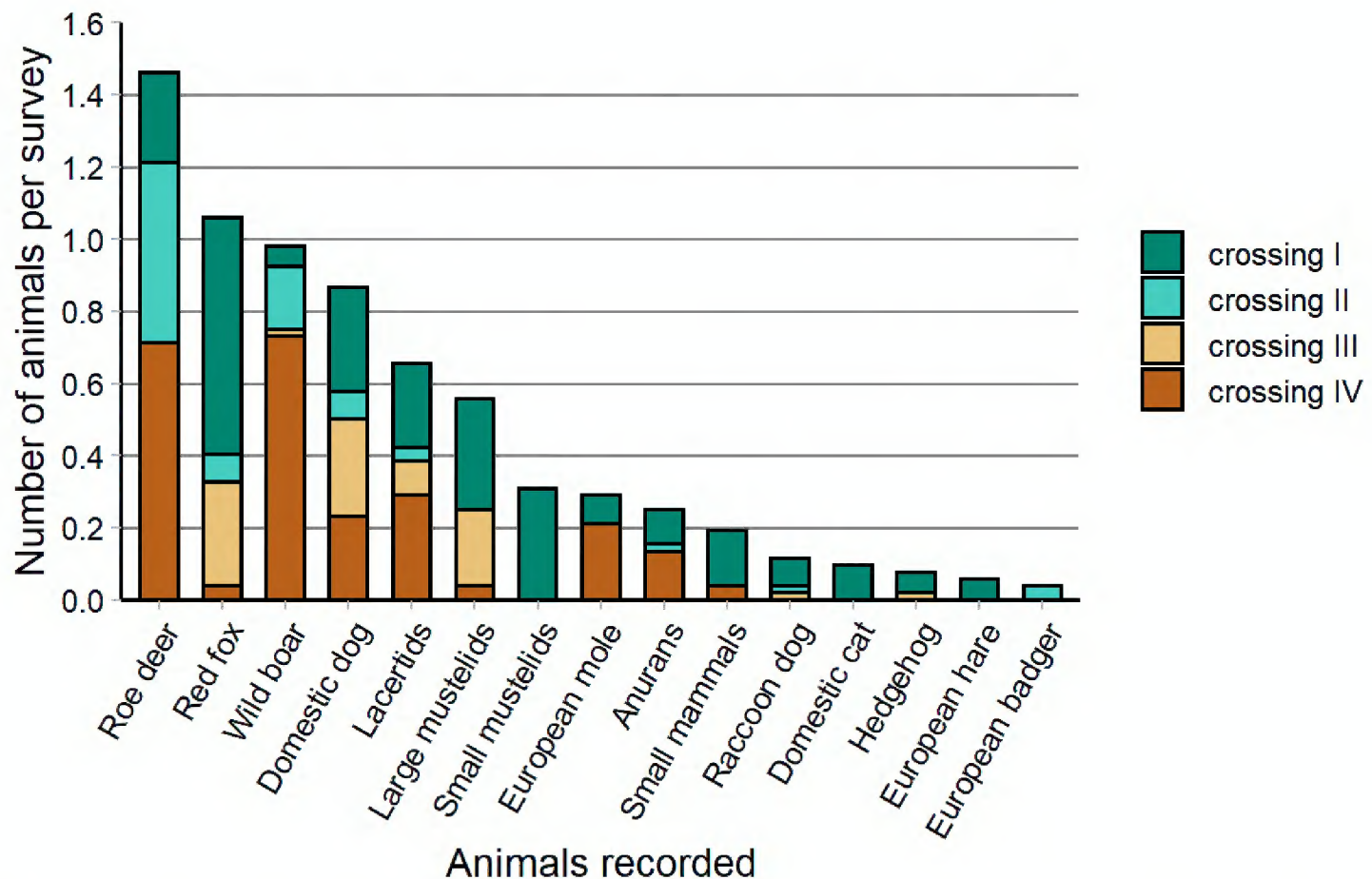


Figure 4. Activity of animals that explored and crossed the S3 expressway underpasses in suburban areas in western Poland.

The differences in the underpass efficiencies are statistically significant ($\chi^2 = 244.92$, $df = 42$, $p < 0.001$). Additionally, underpasses I and IV featured higher values of H index (Table 2).

Individual animal species showed preferences for select underpasses. Wild boar did not select all the underpasses with equal frequency ($\chi^2 = 69.39$, $df = 3$, $p < 0.001$), and the species was most frequently found in Underpass IV. Roe deer more frequently chose underpasses IV and II than I and III ($\chi^2 = 40.53$, $df = 3$, $p < 0.001$). Large mustelids preferred underpasses I and III ($\chi^2 = 23.55$, $df = 3$, $p < 0.001$), whereas small mustelids used only Underpass I ($\chi^2 = 48.00$, $df = 3$, $p < 0.001$).

We discovered a seasonal diversity in wildlife activity in the underpasses ($\chi^2 = 86.251$, $df = 42$, $p < 0.001$; Table. 3). The greatest activity was observed in the spring, and the underpasses were most intensively used in April, May, and June (Figure 5). This activity was reduced by half in winter.

Roe deer revealed higher activity in the spring and summer seasons ($\chi^2 = 19.47$, $df = 3$, $p < 0.001$). Wild boar used the underpasses mainly in spring. In the remaining seasons, wildlife rarely used the underpasses and, in winter, the underpasses were almost unused ($\chi^2 = 43.51$, $df = 3$, $p < 0.001$). Small mustelids were most frequently using the underpasses in summer and autumn. However, in spring and winter, their activity decreased ($\chi^2 = 11.00$, $df = 3$, $p = 0.011$). Moreover, increased activity of domestic dogs was recorded in spring ($\chi^2 = 11.80$, $df = 3$, $p = 0.008$). Half of the total number of the recorded species/groups was found to be inactive in winter (anurans, lacertids, European hare, hedgehog, wild boar, European badger, and raccoon dog) (Table 3).

Table 2. Wildlife activity in the S3 expressway underpasses in suburban areas. All animals observed in the underpasses were counted, including the ones that crossed the road and those which abandoned their attempts.

Animal species / group of species	Crossing								Total	
	I		II		III		IV		N	%
	N	%	N	%	N	%	N	%		
Anurans	5	3.6	1	2.0	0	0	7	5.6	13	3.6
Lacertids	12	8.5	2	4.1	5	10.4	15	11.9	34	9.3
European mole	4	2.8	0	0	0	0	11	8.7	15	4.1
Small mammals	8	5.7	0	0	0	0	2	1.6	10	2.8
European hare	3	2.1	0	0	0	0	0	0	3	0.8
Hedgehog	3	2.1	0	0	1	2.1	0	0	4	1.1
Roe deer	13	9.2	26	53.1	0	0	37	29.4	76	20.9
Wild boar	3	2.1	9	18.4	1	2.1	38	30.2	51	14.0
Red fox	34	24.1	4	8.2	15	31.2	2	1.6	55	15.1
European badger	0	0	2	4.1	0	0	0	0	2	0.6
Raccoon dog	4	2.8	1	2.0	1	2.1	0	0	6	1.7
Domestic cat	5	3.6	0	0	0	0	0	0	5	1.4
Domestic dog	15	10.6	4	8.2	14	29.2	12	9.5	45	12.4
Large mustelids	16	11.4	0	0	11	22.9	2	1.6	29	8.0
Small mustelids	16	11.4	0	0	0	0	0	0	16	4.4
Total	141	100.0	49	100.0	48	100.0	126	100.0	364	100.0
Shannon diversity index H'	3.393		1.183		1.284		2.426		–	

Table 3. Seasonal activity of wildlife in the S3 expressway underpasses in suburban area in western Poland.

Animal species/ group species	Spring		Summer		Autumn		Winter	
	N	%	N	%	N	%	N	%
Anurans	2	1.5	4	3.9	7	8.3	0	0
Lacertids	18	13.0	11	10.6	5	6.0	0	0
European mole	6	4.4	3	2.9	4	4.8	2	5.3
Small mammals	6	4.4	1	1.0	2	2.4	1	2.6
European hare	1	0.7	1	1.0	1	1.2	0	0
Hedgehog	3	2.2	0	0	1	1.2	0	0
Roe deer	23	16.7	32	30.8	15	17.9	6	15.8
Wild boar	32	23.2	10	9.6	9	10.7	0	0
Red fox	11	8.0	14	13.5	17	20.2	13	34.2
European badger	1	0.7	0	0	1	1.2	0	0
Raccoon dog	3	2.2	2	1.9	1	1.2	0	0
Domestic cat	1	0.7	1	1.0	1	1.2	2	5.3
Domestic dog	21	15.2	6	5.8	9	10.7	9	23.7
Large mustelids	9	6.5	10	9.6	6	7.1	4	10.5
Small mustelids	1	0.7	9	8.7	5	6.0	1	2.6
Total	138	100.0	104	100.0	84	100.0	38	100.0
Seasonal %	37.9		28.6		23.1		10.4	

During the monitoring period, we found that rainwater stagnates periodically in underpasses II, III, and IV. However, water did not stagnate in Underpass I. Underpass IV was flooded with water in 17% of control, Underpass II in 77% of control, and Underpass III in 35% of control. The differences in the period of water stagnation in the underpasses are statistically significant ($\chi^2 = 52.701$, $df = 3$, $p < 0.001$). Wild boar

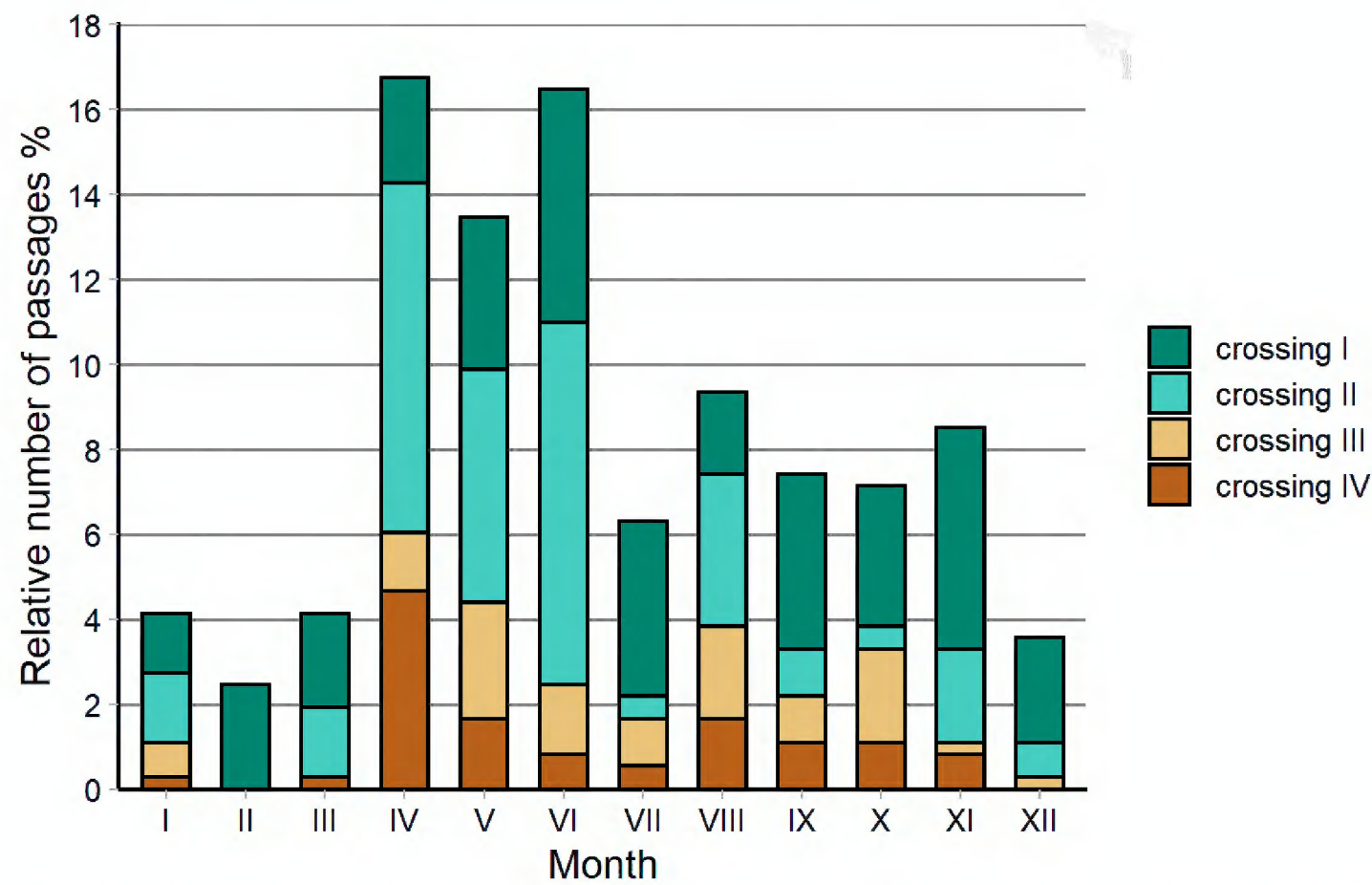


Figure 5. Use of S3 expressway underpasses in western Poland by wildlife that explored and crossed the road.

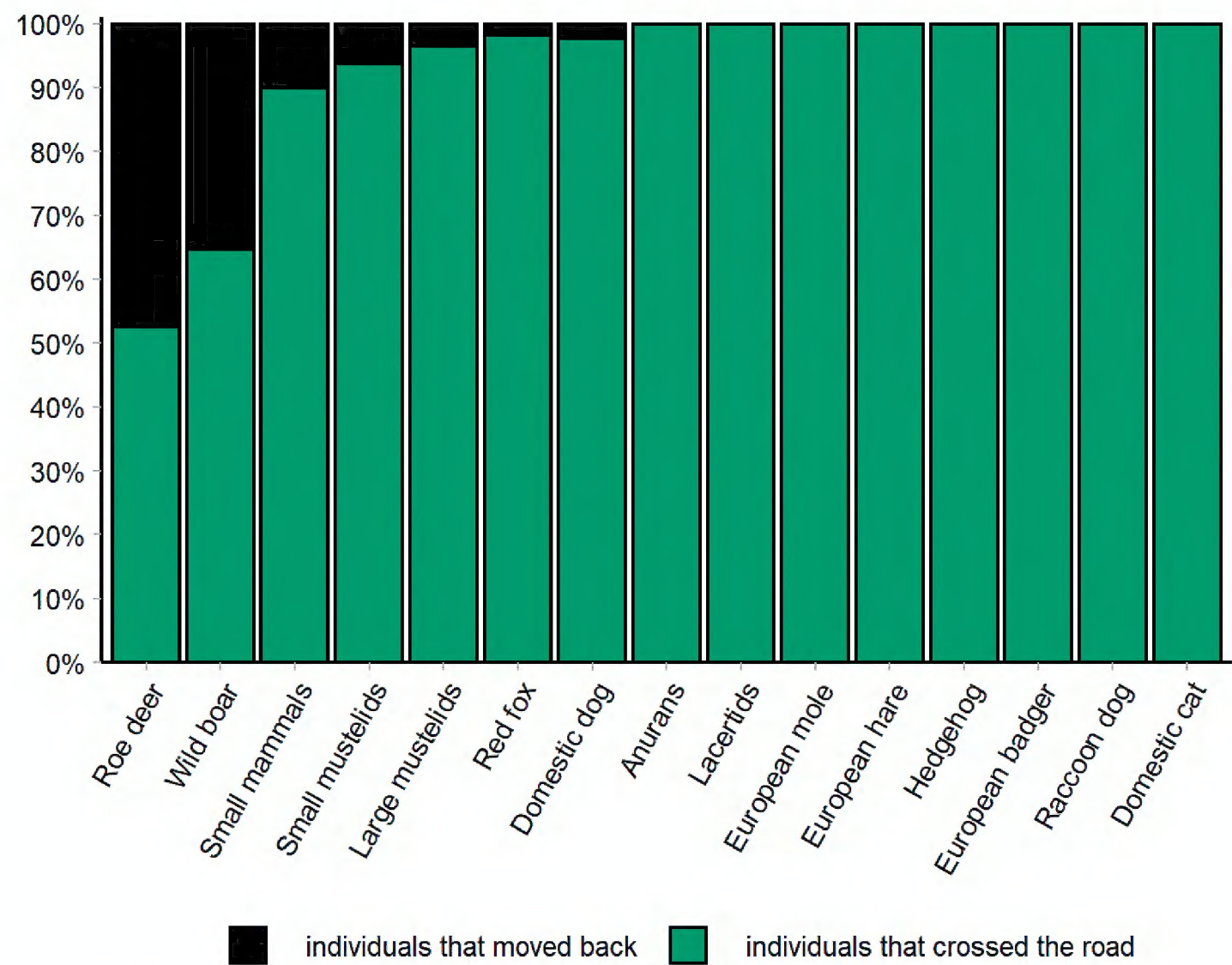


Figure 6. Proportion of animals which crossed and did not cross the S3 expressway using the underpasses.

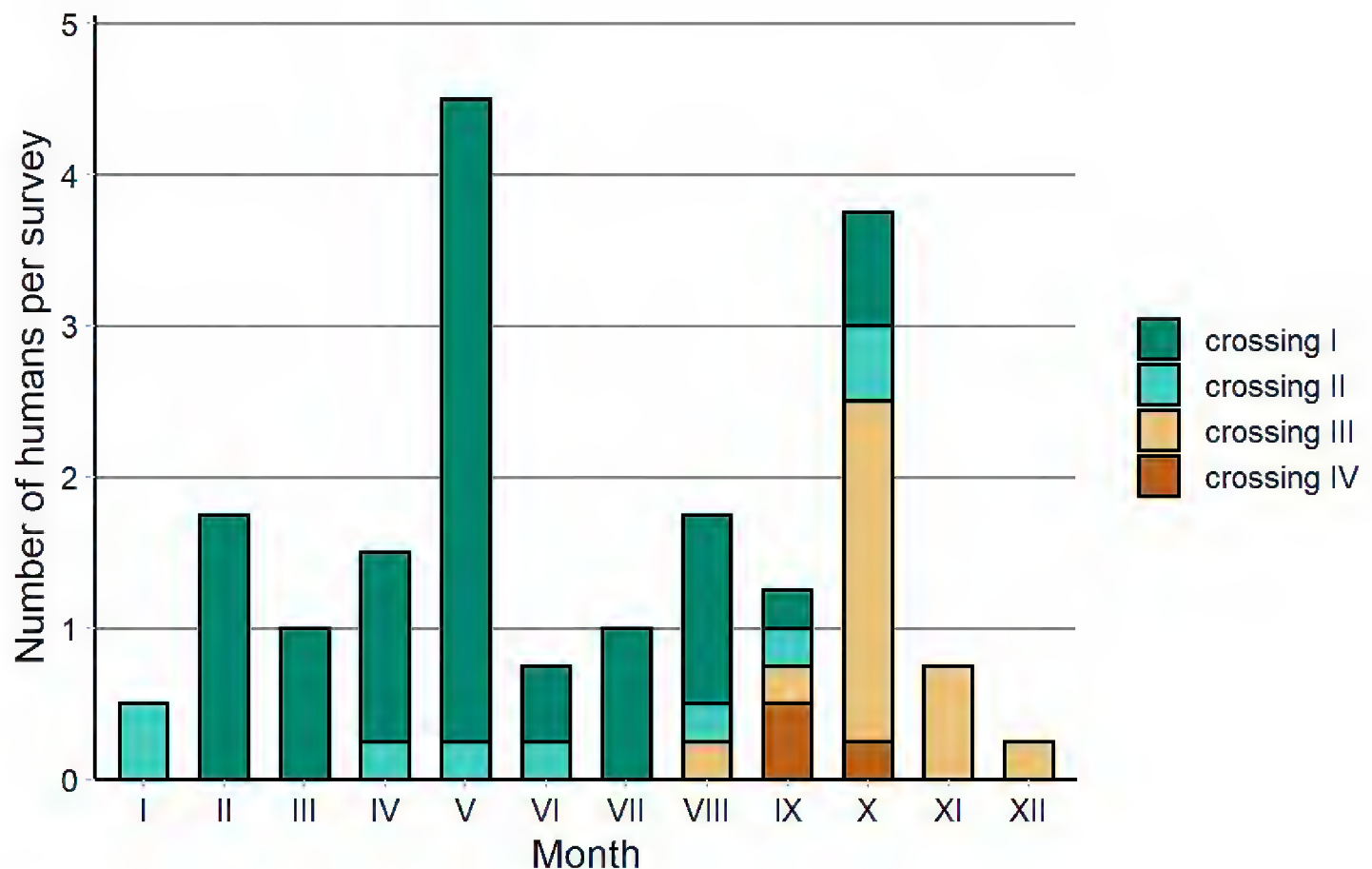


Figure 7. Monthly use of the S3 expressway underpasses by humans.

avoided underpasses where there was stagnating water ($\chi^2 = 46.394$, $df = 3$, $p < 0.001$), whereas roe deer did not reveal any activity alterations and used the underpasses with equal frequency regardless of water stagnation ($\chi^2 = 19.4$, $df = 3$, $p < 0.001$). Only 4% of carnivorous mammals used the underpasses when they were flooded.

Some animals (22%, Figure 6) abandoned their route to the other side of the road through the underpasses. These were mainly roe deer, wild boars, large and small mustelids, small mammals, foxes, and dogs. Among the species that abandoned attempts to cross the road, roe deer (90%) and wild boar (55%) predominated (Figure 5). Underpass IV was the most frequently abandoned crossing.

During the year, we also found human activity in the underpasses (75 persons). People used individual underpasses to a different degree ($\chi^2 = 64.68$, $df = 3$, $p < 0.001$). The largest proportion of footprints (64%) were found in Underpass I, localized closest to the town Zielona Góra. In the remaining underpasses, human activity was lower (Figure 7).

Discussion

Many factors affect the use of underpasses by wildlife, for example, appropriate design, size parameters (dimensions), and appropriate location (Forman et al. 2003, Kleist et al. 2007, Grilo et al. 2008). The results of this study show that underpasses for animals under the fenced S3 expressway were used by wildlife despite their structural features that expose wildlife to noise and car lights. The utilization rate of the monitored underpasses is higher than for similar underpasses in Spain (Mata et al. 2008).

The problem of underpass use by animals is widely studied worldwide in regard to various aspects, e.g., vegetation covering the area near entrances to the underpass, road fencing, and distance to urban areas (e.g. Clevenger et al. 2001, Ascensão and Mira 2007). The final results of monitoring are largely influenced by the specificity of the composition of local wildlife populations. In Poland, all newly built motorways and expressways are fenced and associated with animal passages. It is difficult to compare the results obtained in western Poland with those from other national surveys, although monitoring is carried out for numerous new road investments in Poland. However, scientific institutions or people interested in publishing the results (with the commissioner's consent) rarely participate in such research projects. Therefore, it is difficult to estimate a complete overview of the effectiveness of the constructed animal passes.

There is a significant publication that discusses the usage of underpasses under expressways by wildlife in the mountains in the south of Poland (Mysłajek et al. 2016). The authors indicate a higher efficiency of viaducts, which, on an annual scale, are used more intensively. The results obtained in our research confirm the observations described in the abovementioned publication – that is, the underpasses are most frequently used by roe deer and fox. Red foxes prefer smaller passages and use them more often than other mammals. Red foxes were not sensitive to landscape parameters and road traffic in contrast to roe deer (Seiler and Olsson 2009). In our research, wild boars were frequent users of the underpass. This result is in contrast to observations in mountain areas (Mysłajek et al. 2016).

Furthermore, in western Poland we observed a much smaller difference between the numbers of domesticated and wild species despite the passages being situated in urbanized areas. In southern Poland, domesticated species accounted for 25% of all recorded animals (Mysłajek et al. 2016). In examined underpasses, we noted high activity of domestic dogs, which could deter the activities of wild species. The penetration of dogs into rural areas is a common problem in Poland (Krauze-Gryz and Gryz 2014). Results of other research stress the significant relationship between the distance from urban areas and the usage of passes by domesticated animals. These studies also direct attention to the importance of localization of passes for animals away from urban areas (Ascensão and Mira 2007).

Species of mammals observed in passages under S3 road are characteristic of woodland areas of western Poland (Gabryś et al. 2005). In the underground passages, we did not find any large ungulate mammals (e.g. red deer) due to small dimensions of these passages. The size of the passage is of key importance here, because the red deer prefer larger openings (Ballók et al. 2010). Moose *Alces alces* can be seen in the immediate vicinity of the road. In the close neighborhood, there were some attempts by moose to get into the road lane despite the security measures applied (Ważna et al. 2014). After finishing our research, the S3 expressway was rebuilt. New overpasses for large mammals were created and the situation on the road has improved. This is very important also for the wolf *Canis lupus* population, which is now expanding in western Poland (Nowak et al. 2017). The species was not observed in our research,

which can be explained by both the type of passages and the vicinity of the city. Some species observed in passages occurred rarely as a result of the local population size. The population of the hare in Poland is low, especially in forest environments (Kamieniarz et al. 2013). Badgers prefer fertile mixed forests and are rarely found in poor pine forests (Kowalczyk et al. 2003). Similarly, hedgehogs *Erinaceus* spp. prefer open suburban areas (Reeve 1994). We did not observe tracks of the red squirrel *Sciurus vulgaris*, either, despite the passages being situated in forests.

The use of underpasses by roe deer and wild boar is surprising because the underpasses were intended for small- and medium-sized animals and underpasses I, II and III were characterized by low openness ratio index. Underpass IV was used most frequently by roe deer and wild boar possibly due to the higher value of openness ratio index. Nevertheless, we confirmed the observations of Mata et al. (2008) that small passages reduce the barrier effect for these species. Roe deer seems to be a species with a high adaptability to difficult conditions of mobility. It has been observed that during summer heat, the roe deer stay in the small amphibian crossings under highway during the day, thus protecting themselves from the sun (Skierska and Cichocki, own observations). Various studies found that many animals use drainage culverts even though they were not originally designed for wildlife. They are important for animals for the crossing of the roads (Ng et al 2004). Small drainage culverts were used by North American species, such as cervids (e.g. mule deer *Odocoileus hemionus*) or large carnivorous mammals (e.g. black bear *Ursus americanus*, bobcat *Lynx rufus*) (Clevenger and Waltho 2000, Krawchuk et al. 2005, Marangelo 2019). However, drainage culverts cannot replace conventional wildlife passages for mammals, mainly because the high-water levels and the use of polyethylene as construction material decrease the number of successful passages. Only half of the species observed outside of the drainage culverts were detected making full crossings (Brunen et al. in press).

The results of our study indicate significant seasonal differences in the use of animal passages. The examined road underpasses were used most intensively in spring and least frequently in winter. The results confirm the observations made by Mysłajek et al. (2016), where analogous relationship was reported. Furthermore, it is associated with a reduced tendency of wildlife migration and road crossing in winter (Kämmerle et al. 2017). In winter, no individuals of some species were observed in the underpasses because, in Central Europe, many animals hibernate in winter (anurans, lacertids, hedgehogs, etc.) or show reduced activity (European badger, raccoon dog, etc.). From spring to autumn, animals are more active due to the seasonal breeding and rearing the young. In addition, in autumn, the recorded annual sizes of animal populations reach the maximum numbers (e.g. red fox population) (Goszczyński 1989). In Western Europe, where the climate is warmer, seasonal differences are less distinct (Yanes et al. 1995, Ascensão and Mira 2007, Mata et al. 2009).

The results of this research indicate that a large proportion of animals that attempt to move through the underpass under a road abandon these attempts. Standard monitoring with the use of strips of sand did not allow us to record the number of animals that turned back before traversing the passage. We assume that animals that

have passed through the monitored strip and turned back, in some cases, might have been even counted twice. Villalva et al. (2013) reported that the use of underpasses that remain flooded for most of the year (more than 3 cm of water-depth) is less frequent than the use of dry passages. In our studies, only a small percent of carnivorous mammals used the underpasses when they were flooded. Especially foxes and badgers prefer culverts that are dry throughout the year (Villalva et al. 2013). In our study, underpasses with stagnating water were also avoided by wild boar.

Human presence, moreover, has an impact on the use of underpasses. The fewer people use an underpass, the more animals tend to use it (Grilo et al. 2008, Barrueto et al. 2014, Clevenger and Barrueto 2014). In our study, people most frequently used the underpass I, which was localized near the city. The interference by humans could have had a negative effect on use of the passage by ungulate species. People most frequently used the underpasses in May and October. In May, the temperatures rise in this part of Europe and, therefore, city residents eagerly choose activities in surrounding forests. In October, on the other hand, human activity increases due to the tradition of mushroom picking. In the remaining months of the monitoring, human activity was distinctly lower. In May and October, we observed lower numbers of wildlife in the underpasses in comparison to other spring and autumn months.

The obtained results indicate the importance of planning and construction of animal passages even in urbanized areas which do not display unique natural characteristics. Underpasses are an important element to prevent the isolation of local populations and, presumably, could reduce the negative impact of urban development.

Acknowledgments

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